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IMPLEMENTATION OF FULLY COUPLED HEAT AND MASS TRANSPORT MODEL TO DETERMINE THE BEHAVIOUR OF TIMBER ELEMENTS IN FIRE

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ABSTRACT: In this paper we present results of numerical analysis of timber beam exposed to fire. The numerical procedure is divided into two physically separated but closely related phases. In the first phase coupled problem of moisture and heat transfer over the timber beam is numerically solved using the enhanced finite element method. The results of the first computational stage were used as the input data for the numerical analysis of mechanical response of timber element.

KEYWORDS: fire, fire resistance, timber beam, heat and mass transfer model

1 INTRODUCTION

From the fire safety point of view timber is relatively favourable material. The behaviour of timber in fire depends on a large number of phenomena that occur when it is exposed to elevated temperatures. The behaviour of timber in fire depends on a large number of phenomena. In an accurate model, for estimating the response of timber elements in fire, these, must be accounted for. A major problem is the pyrolysis associated with charring of timber. At temperatures above 300°C timber starts to char which leads to changed thermal and mechanical properties. In addition it is necessary to carry out temperature-moisture analysis of timber element exposed to fire in order to determine its response.

In an open porous hygroscopic material such as wood heat and moisture transport is a complex system of coupled processes. Inside timber, different phases of water can be observed, i.e., free water, bound water and gas phase of water (water vapour and air). Conservation equations for each phase with the exchange of mass between the different phases have to be considered. Different transfer phenomenon’s can be applied for each phase. The equations describing the conservation of mass must also be supplemented with an equation describing the conservation of enthalpy [2].

2 NUMERICAL ANALYSIS

Mechanical behaviour of timber elements in fire is very complex phenomenon where the temporal and spatial distributions of temperature and water content of wood play a decisive role. The deformation of the structure does not significantly affect the moisture and heat transfer. Therefore, the numerical procedure is divided into two phases. In the first phase the time development of the moisture and temperature state of the timber element is calculated. The results of the first computational stage are used as the input data for the numerical analysis of mechanical response of timber elements.

2.1 THERMAL ANALYSIS

The bound water transfer model is assumed to follow Fick's law [1]. More complex is the transfer of gaseous mixture. Transfer of water vapour and air has to be combined by a convective and diffusive model of transport. For the convective part Darcy's law is usually applied and for the diffusive part Fick's law is used [2]. The free water constitutive relation is usually assumed to follow the generalized Darcy's law [3]. All three processes are connected with each other through the exchange of mass between the different phases, i.e., the phase change

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of vapour to free water and vice versa (condensation and evaporation), the phase change of vapour to bound water and vice versa (sorption) and the phase change of free water to bound water and vice versa. Thermal interaction on mass transfer is seen as temperature dependent diffusion coefficients where Fick's law is applied and temperature dependent mass velocity where Darcy's law is used as well as the Soret effect. The energy conservation equation takes three phenomena into account. Firstly, the usual conduction of heat thru solid, described by Fourier's law. Secondly, the changes in enthalpy resulting from change of phase, i.e. sorption, evaporation and condensation. And finally, the convective transfer of heat, i.e. the effect that heat is carried by the mass flux. These equations with corresponding initial and boundary conditions are generally non-linear and can rarely be if at all solved analytically. Therefore, numerical methods have to be employed.

2.2 MECHANICAL ANALYSIS

The presented finite element formulation is based on Reissner's kinematically exact model of beam where large membrane and flexural deformations are allowed [3]. The geometric extensional strain is a function of extensional strain of centroidal axis ε and its pseudocurvature κ. The Bernoulli hypothesis is considered. An important assumption in this model is the additive decomposition of the increment of geometric extensional strain. The system of equations for finite element method is written based on modified principle of virtual work where quantities ε and κ are interpolated over finite element by Lagrangian polynomials. A more detailed description of the finite element formulation is presented in [4].

3 PARAMETRIC STUDY

With the presented numerical model impact of parameters such as the effect of bound water diffusion, water vapour diffusion and temperature dependent sorption on mechanical response is investigated. Particular attention is focused on the impact of diffusion of bound water on the mechanical response. We analyze if, in certain cases, diffusion of bound water can be omitted. Therefore in this context, the numerical model can be simplified with only one diffusion equation.

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